AD-758 263

CODING SYSTEMS IN PERCEPTION AND COGNITION

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Prepared for :

Air Force Office of Scientific Research
Advanced Research Projects Agency

1 December 1972

1.

CODING SYSTEMS IN PERCEPTION AND COGNITION

A Final Technical Report on a Five-Year Project*

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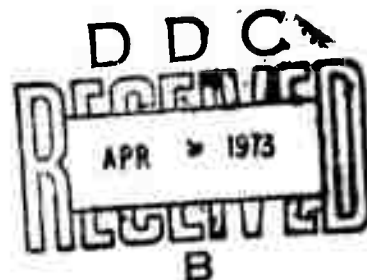Period of Project: 1 August 1967 through 31. August 1972

Amount of Money: $1,446,203

December 1, 1972

*Actually, this report covers two contracts: Contract F44620-67-C-0099 (from 8/1/67 through 8/31/71) and Contract F 44620-71-C-0126 (from 9/1/71 through 8/31/72). The final report for the first contract was submitted at the end of the four year contract period. Technically, this final report deals with the second contract. However, we have found it feasible to report the accomplishments for the entire five-year period of both contracts at certain places in this report. A common bibliography and key word list, for example, is provided to cover the entire period covered by both contracts.

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
University of Oregon Department of Psychology Eugene, Oregon 97403	UNCLASSIFIED
	2b. GROUP

3. REPORT TITLE

CODING SYSTEMS IN PERCEPTION AND COGNITION

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Scientific   Final

5. AUTHOR(S) (First name, middle initial, last name)

Ray Hyman

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
1 December 1972	77	135 plus 56 talks

8a. CONTRACT OR GRANT NO. F44620-71-C-0126	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. AO 966	
c. 61101D	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d. 681313	AFOSR - TR - 73 - 0530

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
TECH, OTHER	Air Force Office of Scientific Research 1400 Wilson Boulevard (NL) Arlington, Virginia 22209

13. ABSTRACT

The variety of experiments completed under the contract successfully isolated ways that humans encode and employ information to meet task demands. The results indicate that, when a stimulus is presented, two or more separate coding processes proceed in parallel. One process may build up an iconic representation of the stimulus object; another process is the retrieval of one or more name codes for the stimulus pattern. For some tasks the response depends completely on the iconic code; for others it depends on the name code. Not only do humans typically convert iconic codes into name codes (abstraction), but, when the occasion is appropriate, they can reverse the process and generate iconic representations from name codes. The build up or construction of the iconic representations appears to take place in a three-dimensional analog medium. The particular representation that is achieved is dependent upon a hill-climbling procedure that is guided by the minimum principle. The build up of information apparently proceeds independently of the individual's state of alertness. Alertness affects the speed of response by changing the subject's criterion for responding. Under high alertness he is willing to respond with less information. Speed of responding can also be affected by selectivity. Selectivity operates on particular aspects of a stimulus enabling the subject to begin constructing some aspects of the representation prior to actually receiving the stimulus (expectancy). Alertness increases speed at the expense of errors; selectivity increases speed without increasing errors. Work also progressed on the third component of attention--conscious processing.

DD FORM 1473
1 NOV 65

UNCLASSIFIED

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Coding Systems						
Perception						
Cognition						

FINAL TECHNICAL REPORT*

CODING SYSTEMS IN PERCEPTION AND COGNITION

ARPA Order 966
Program Code 1D20
Under Contract to: The State of Oregon acting by and through
the Oregon State Board of Higher Education
on behalf of the University of Oregon

Effective Date: 1 September 1971
Contract Expiration Date: 31 August 1972
Amount of Contract Dollars: $154,872
Contract Number: F44620-71-C-0126

Principal Investigator: Ray Hyman
Professor of Psychology
(503) 686-4910 or 686-4962

Title: Coding Systems in Perception and Cognition

Sponsored by: Advanced Research Projects Agency
ARPA Order No. 966

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*This contract is a continuation of Contract F44620-67-C-0099 of same
title. The key facts of that contract:
ARPA Order: 966
Program Code: 0D20
Under Contract to: same as above
Effective Date: 1 August 1967
Expiration Date: 31 August 1971
Amount of Contract Dollars: $1,291,331
Principle Investigator: same as above
Sponsor: same as above

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2.0. Technical Report Summary

The purpose of the project on Coding Systems in Perception and Cognition was to bring together and focus upon a common theme the skills of experimental psychologists in perception, psychophysics, memory, attention, and human performance. The common theme was the way humans represent or code information in order to accomplish a variety of tasks. When the project was initially proposed in 1966, the experimental work on human performance was already making it clear that humans code information in a variety of different formats--visual, auditory, articulatory, kinesthetic, symbolic or verbal. Moreover, these different codes seemed to differ in a variety of ways that could be important for various task demands. We wanted to investigate such questions as which codes were most effective for various tasks and situations; to what extent is the employment of one code rather than another optional; how do the codes interact with one another in various tasks; what is gained and what is lost in converting from one code to another; etc.

More specific objectives were spelled out in our contract as follows:

"1. Conduct research on the interaction between coding systems and stimulus events in perceptual and cognitive tasks in human subjects.

"2. Conduct experiments on perceived tridimensionality, spatial coding, similarity grouping, and pitch as a medium in which patterns occur.

"3. Construct and test a general model of human pattern recognition.

"4. Conduct research on immediate recall, semantic memory, and the effects of similarity and repetition on memory.

"5. Conduct research on human performance, including experimental
    studies of attention, memory storage, memory retrieval, move-
    ment control, motor skills, and pattern recognition."

Just about all of the experiments in the project deal with the first
objective in one way or another. Posner's work on abstraction and genera-
tion is an especially good example of how we tackled this objective. In
dealing with a stimulus pattern our results suggest that two or more coding
processes may proceed in parallel. One process, for example, is a build
up or construction of an iconic representation of the stimulus; another
is the contact or retrieval of one or more "name" codes for the stimulus
pattern. Posner and his colleagues have learned a great deal about how
these codes function by devising techniques which enable us to separately
manipulate or affect these different codes. For some tasks the subject
depends completely upon the iconic code; for other tasks he needs to
employ the name code. When our project began, it was assumed by many in-
vestigators that processing inevitably went from an iconic code to a name
code. The results from our studies indicate that the process can go in
the reverse way (generation) as well.

The second objective has been the focus of all of Attneave's work
on this project, as well as some of the work of Beck. Attneave's experi-
ments on tridimensionality have lead to a model of how humans represent
perceptual information at the preprocessing stage. The evidence strongly
suggests that this representation is analog (rather than digital) in
nature. Of the infinite number of representations of a stimulus pattern
that can be constructed, the human perceiver seems to achieve that repre-
sentation that minimizes a "description" of the pattern within a three-

dimensional, Euclidean framework. As a general principle, the minimization principle has little predictive value because it is not always obvious what the system is minimizing and with respect to what criteria it guides such minimizing. But Attneave has made considerable progress in defining what will be minimized within specific task situations. The findings seem to have surprising generality, including not only tasks involving directly perceiving tri-dimensionality in projective drawings, but in tasks involving ambiguous figures, and similarity grouping.

The third objective of testing a general model of human pattern recognition has been tackled by Hyman and his colleagues, building upon the previous and concurrent work of Attneave, Posner and Keele. The original model, postulating three successive and overlapping stages in pattern mastery has not fared well in the face of data resulting from a series of experiments. The work is continuing with the attempt to fit a new model to the data. In general, however, the data suggest that subjects employ both an analog and digital coding system simultaneously in learning to classify stimulus patterns into one of two categories. The "digital" component of the system corresponds to what Attneave calls a "schema" and Posner and Keele refer to as a "prototype". The subject seems to abstract from various representatives of the category an idealized or "composite" prototype of that category. Subsequent patterns are then classified or identified in terms of how similar they are to one of these idealized prototypes. The "analog" part of the process refers to the continuum or space within which the subject detects degree of similarity and dissimilarity to prototypes. When the model is more fully worked out,

we hope it will give us a way of reconciling models of coding that are based on continua or analog metaphors and those which are based on discontinuities or digital metaphors.

The fourth objective has been tackled by a variety of experiments in memory by Reicher, Hintzman, Schaeffer and Wickelgren. Hintzman's findings show that subjects store many other aspects of a memory task than just a list of items which vary in strength--they can retrieve information about the frequency, spacing, and modality of such items as well. While such work implicates a variety of more or less separate trace columns in which the various occurrences of the "same" items are stored, Wickelgren's work focusses upon how the repetitions of the "same" item increment some single surrogate or representative for that item. This problem of remembering the unique setting in which an item occurs as opposed to storing that item in a single location comes up in a variety of ways in our work. The so-called logogen model which Keele employs has to deal with this problem and it is intimately related to the iconic and name codes that Posner studies.

The fifth objective, like the first, cuts across almost all the experiments we have conducted. But the work of Posner and Keele is especially pointed towards this objective. Keele's work seems to point to a system in which memory retrieval is automatic and in parallel and in which various bottlenecks in performing a skilled task occur at the level of movement control. At the level of human thinking, Posner has shown how our various experiments on memory codes, memory organization and mental operations can be brought to bear upon how humans solve

problems. The key concept is that of the working memory in which information retrieved from long-term memory is brought into conjunction with information in short-term memory which depends upon immediate stimulation. It is the limited capacity of this working memory that constrains how well the individual will be able to bring his knowledge to bear upon a given problem. The thinker's task is to get just that combination of informational items into working memory that can solve the problem. Very frequently, the thinker has all the information available for the solution, but he fails to solve the problem because he does not manage to assemble the information in such a way that it can be grasped or combined as a unit. Posner, in his forthcoming book, shows how the kinds of experiments we have done in this project can be helpful in pointing the way towards both theory and techniques that will suggest how to help the thinker overcome the constraints of his working memory.

In addition to the many findings that have emerged from our many experiments, the project resulted in the development and perfection of a number of methodological tools for studying coding systems. Fagot's work on separately testing underlying assumptions when using human subjects as measuring instruments, Attneave's method for studying tri-dimensionality, Posner's matching procedures and his new techniques for studying the physiological concomitants of preparation, Schaeffer's and Conrad's methods for assessing semantic structures and Warren's technique for detecting how far abstraction has proceeded are just a few of the many new tools, techniques and paradigms that we have developed. Our most important methodological achievement was the construction and development of an automated

laboratory based upon the two laboratory computers we purchased under this contract (a PDP-9 and a PDP-15). About 70% of the research was controlled by this laboratory. Now that we have finally obtained a permanent place to house this laboratory, we expect that this facility can serve almost all of our experimental psychologists who will continue, under various governmental grants, to build upon the work that was initated under this project.

It is, of course, impossible to summarize all the findings from such a fruitful project that already has produced a bibliography of more than 130 items and will eventually result in anywhere from 160 to 200 published documents. Fortunately, many integrative summaries are or will soon be available of large portions of our work. In addition, the principal investigator hopes to write a later integrative summary of the project when sufficient time has elapsed to allow much of the un-completed work to be finished and to digest the implications of the work as a totality. Meanwhile, the present final technical report will give a very general overview and point to particular studies that will help provide partial integration of our work. As an aid to the reader, in addition to a regular alphabetized bibliography of our work, we also provide a cross-referenced listing of our work under various key words.

3.0. Introduction

Our initial proposal to do research on Coding Systems in Perception and Cognition described our intentions in the following words:

"The proposal deals with the interaction between coding systems and stimulus events in perceptual and cognitive tasks. This interaction is viewed as a reciprocal relation between the form of the coding system and the characteristics of the stimulus event. On the one hand, we want to investigate the ways in which the characteristics of the coding system are determined by the qualities and organization of components of the stimulus event. On the other hand, we want to study how the efficiency with which an individual operates upon the stimulus information is determined by the characteristics of the coding system which he employs in the situation. The general plan is to attack this issue by means of a series of different, but closely coordinated, research projects. The projects will individually investigate the same problem from a variety of different viewpoints--form perceptions, multidimensional psychophysics, scaling, decision and choice theory, concept learning, skill learning, inductive logic, and problem solving. We will coordinate the projects by means of several devices: 1) the formulation and application of a common terminology, notation, and system of concepts; 2) the use of identical stimulus sets; 3) the use of common tasks, dependent variables, equipment, and experimental designs; 4) the rotation of research assistants among projects; and 5) a single individual as principal investigator who has the authority to decide,

at each choice point, whether a given experiment does or does not directly contribute to the overall goal of helping us understand how the characteristics of a coding system affect an individual's ability to use information in perceptual and cognitive tasks."

Those intentions were written approximately seven years before this present report. The Final Technical Report on Contract F44620-67-C-0099 summarized what we did during the first four years of our project to fulfill these intentions. The present Final Technical Report (on Contract F44620-71-C-0126) attempts to convey what we accomplished over the five-year period spanned by both contracts on Coding Systems in Perception and Cognition.

Ideally, this final report would consist of an integrated presentation of our findings about how coding systems operate in human performance. Instead, the report will fall far short of that ideal. One reason is that this report has to be written only a short time interval from the end of the contract. This does not allow time for appropriate digestion and interweaving of the more than 130 written documents that have already been completed on the basis of research supported by the project. Also, many of the experiments supported by the project have not yet been brought to completion. Some are waiting to be written up; others still are in the data-analysis stage; and many projects started under the contract are being continued under other auspices. So the full story is not yet in.

Consequently, this report will suggest the direction of the final integration without actually providing it. Fortunately, some of the monographs already written by some of the investigators or being planned by them provide at least partial integrations of large segments of our

work. Also, the principal investigator hopes to write a fuller and more integrated summary of the overall project at a later date when most of the returns will be in and when sufficient time has occurred. As a step in this direction he will conduct a graduate seminar in the Spring of 1973 whose objective will be to develop an integrated overview of our accomplishments on this project.

Because the bulk of the work on this project originates with the human performance tradition, integrating much of this work within a common framework will not be too difficult. Indeed much of this integration has already been accomplished in Steve Keele's book <u>Attention and Human Performance</u> and Posner's forthcoming book on <u>Memory and Thought</u>. Between them, these two books provide an integrated framework within which to organize the experiments of Reicher, Schaeffer, Posner, Keele, Hintzman and their associates. All of the experiments done by these investigators under this project fit naturally into the human information processing viewpoint.

But this still leaves the work of Attneave, Beck, Fagot, Wickelgren and their associates to be brought into the picture. The work of these latter investigators, although also oriented towards coding systems, originates in different traditions. Attneave and Beck represent the more classical approach to perceptual problems, especially those problems of organization, segregation and patterning that the Gestalt psychologists challenged us with. Attneave pioneered in the application of information theory to Gestalt problems such as that of "good figure". But this aspect of information theory stems from Claude Shannon and emphasizes the

description and quantification of structures or sets of possibilities.
But the information processing conceptions used in the human performance
area stem more from cybernetics and modern computer programming. This
latter viewpoint emphasizes the flow of information from one isolable
subsystem to another rather than the specification of the ensemble of
possibilities at any one point in the process. Perhaps for this reason
the way to integrate Attneave's work with that of Posner and Keele has
not yet been resolved to our satisfaction. But the direction that such
an integration will take seems discernible. Within our current framework,
Attneave and Beck, and to some extent Fagot as well, focus on the dynamics
and structure of the coding process that occurs at a single stage, in this
case the preprocessing or preselection stage. The major concern is with
how the stimulus information is represented _prior_ to contact with memory.
The human performance viewpoint tends to take this stage for granted
because it is interested not in specifying what goes on at a particular
stage, but rather in describing the flow of information between stages.
In other words, it is more concerned with the interfaces between components
of the system rather than in the components themselves.

Fagot's work on the psychophysical law is even more difficult to fit
into the total picture. In this case, the problem might be that the task
given to subjects in these sorts of studies is rather an unnatural one.
The subject is asked to make focal what is ordinarily part of the background.
But what is relevant to the other research projects is the methodological
achievements of Fagot and his associates in showing us how to employ
subjects as calibrators of their own phenomenal experience. Independent
of the substantive contribution, this work on the psychophysical law has

produced tools and techniques for knowing when subjects are estimating magnitudes according to some meaningful measurement process. The work has also resulted in interactive computer procedures for fitting a variety of functions to data. Both these latter contributions have already proved valuable in enabling investigators such as Hyman to use subjective data in rigorous fashion and to fit complicated models to the output.

Wickelgren's work stems from still another tradition that is not easy to integrate with human information processing. That is the classical associationistic tradition with its emphasis upon strength and decay of associational traces. Again, without claiming to have achieved a satisfactory resolution, we can see glimmerings of how this integration with the other work may take place. Keele and Posner, among others, have been making increasing use of Morton's Logogen concept to describe certain aspects of the coding of information in their experiments. This logogen concept, in turn, behaves very much like a concept in the associationistic theories of Wickelgren in that inputs referring to the same concept, regardless of specific differences in modality and form, add increments of strength to that concept.

In the following parts of the report we will briefly indicate some of the major themes or focii around which the final integration will be made. We begin with Attneave's work on tri-dimensionality and minimum principle. This work in itself can serve as the basis for integrating the contributions of Beck, Hyman, and Fagot to some extent. It focusses on coding and perceptual dynamics that are preprocess in the sense that contact with memory is not necessarily involved. The next section deals

with Keele's work, especially with his book on <u>Attention and Human</u> <u>Performance</u>. This book integrates much of the work done by Reicher, Hintzman, Posner, Keele and their associates. Keele's book overlaps with, as well as complements, Posner's forthcoming book on <u>Memory and</u> <u>Thought</u>. Posner's work is the topic of the next section. In a very real sense, Posner and his associates provide the cement that binds the whole project together. The emerging theory from Posner's work comes closest to including all of the experimental research conducted under this project. Indeed, this principal investigator believes that if he can comfortably mesh the work of Attneave with that of Posner, he will have solved the problem of how to completely integrate all of the project. Posner's work is followed by a brief account of the still unfinished work of Hyman and his associates on pattern recognition. This work and its emerging theoretical formulation is seen as one way in which the bridge between Attneave and Posner might be built. Finally, in our overview of experimental results there is a brief section on the contributions by the remaining investigators and some suggestions as to how their work will fit into the ultimate unified picture.

We then say a few words about our automated laboratory and about the number and variety of people who have contributed to this project. This is followed by a few words on the ramifications and implications of our work.

Jacelyn Weddell, under the supervision of the principal investigator, prepared the key word section under which the various articles are cross-referenced.

4.0. Accomplishments

During the five years of the project we accomplished many things.
We had special classes and colloquia; we constructed the automated
laboratory and developed it into a unique and effective facility; we
produced many MA theses and Ph.D. dissertations; we gave talks at con-
ventions, meetings and universities all over this country and abroad;
we brought in visitors as visiting scholars, speakers, or consultants;
we produced many publications and more are on the way; and we completed
many experiments with a variety of results. In this section the ac-
complishments we speak about will be those related to the results of
our experimental research.

4.1. Analog Systems and Preprocessing: the work of Attneave

The work of Attneave on this project has been particularly satis-
fying because it has lead to an unexpected integration of a wide range
of perceptual phenomena--ambiguous figures, figure-ground, depth perception;
"pragnanz", etc. A good start at getting the flavor of this integration
is Attneave's Scientific American article on multistability in perception
(1971). A more systematic summary of his work and his emerging ideas about
the minimum principle and its operation in perception is his chapter on
"Representation of Physical Space" (Attneave, 1972). The article on
"Triangles as ambiguous figures" (Attneave, 1968) provides an excellent
illustration of the power of Attneave's ideas about an internal Cartesian
coordinate system in dealing with a rather challenging perceptual pheno-
menon.

The coding system that Attneave has been studying is one that operates
at the preprocessing level. Even before it contacts memory, the stimulus

input is coded and organized in a rather sophisticated way. Of all the
ways in which the same stimulus input can be repre ited, that way which
minimizes complexity with respect to a hypothetical internal reference
system is selected. This internal reference system, as revealed by
Attneave's experiments, appears to be a three dimensional, Euclidean
coordinate system with preferred axes corresponding to phenomenal vertical,
horizontal and front-back. It is a continuous analog medium within wh ch
simplifications, according to a principle of perceptual economics,are
made even before contact is made with memory. Once memory is contacted,
of course, further revisions and interpretations can be carried out on
the stimulus material. But Attneave's work emphasizes what the Gestalt
psychologists also wanted to emphasize; much of the important operations
upon stimulus input occur prior to the operation of "experience" in terms
of past associations.

What is pleasantly surprising about this analog coding system is its
universality. It seems to be importantly implicated not only in almost
all those tasks that are classically referred to as "perceptual", but
also in many other tasks that are considered to be cognitive and require
problem solving.

4.2. Attention and Human Performance: the work of Keele

Keele's book on Attention and Human Performance (1973) presents a
framework and theory around which much of the work of this project can
be organized. Keele organizes the book around the processing tasks of
storage, retrieval and movement. A central feature of this book is the

theory of attention that Keele develops on the basis of his own work and much of the work conducted on this project. Both the storage of information and the operations made upon information require attention according to Keele's theory. But the retrieval of information from memory does not require attention. Among the advantages of such a system is that the selective mechanism of attention operates/information that is activated in memory rather than on sensory information itself. Sensory information that is meaningless, for example, will not contact information from memory and thus, will not furnish the selective system with anything to operate upon.

Keele's theory relies upon 'Morton's logogen model. In this case the logogens, corresponding to concepts, are what are activated by sensory inputs. Those logogens which receive sufficient input above a preset threshold are activated sufficiently to be retrieved in memory. Sensory input goes to a set of logogens in parallel. The bottleneck in performance of a given task does not come about because of the number of logogens which happen to be activated. Rather, it occurs as a result of the operations which are subsequently performed upon those logogens which have been activated. Operations require attention; only one operation can be applied at a time.

Keele applies his theory to a wide variety of phenomena ranging from the Von Restorff effect through semantic memory to social applications such as noise control. The book provides not only a coherent view of Keele's own contributions to our project, but it also encompasses about a third of the research conducted under this project.

4.3. The Interfacing of Systems: the work of Posner

Posner's work and emerging theoretical framework has been central
to this project. The many ways in which Posner's ideas, paradigms,
methods and techniques have provided links to all the other investi-
gators and students on our project were detailed in the Final Technical
Report for the first four years. Even more so than Keele's book,
Posner's forthcoming book on "Memory and Thought" provides a framework
within which one can organize much, if not all, of the various experi-
ments on the project. While Keele's book organized the material on
human performance in its strict and narrower sense, Posner applies the
same sorts of principles to the more complex and broader area of human
thought and cognition. As a result he casts a broader net. To Keele's
coverage, Posner adds the work of additional investigators such as
Attneave, Schaeffer, Beller and their associates. Together, Keele's
and Posner's books provide a framework for integrating just about all the
work on the project with the possible exception of Fagot's work and some
of Beck's and Attneave's work.

In 1964, Holt wrote an article "Imagery: The return of the ostracized."
(American Psychologist, 1964). The return of the "ostracized" could equally
be applied to the concept of "consciousness". Much of Posner's efforts
during the five-year project have contributed to the return of "conscious-
ness" as a viable topic for experimental psychology. What was once banished
for being so elusive has now gained respectability because of the new "mental
chronometry" which enables us to operationally specify when a mental opera-
tion does or does not involve conscious processing. Posner and Keele in

their paper on "Time and space as measures of mental operations" (1970)
make an important distinction for the problem of measuring mental operations.
Operations may require both time and "space". An operation requires "space"
if it interferes with the performance of other voluntary activities. .
Whether an operation requires space can be measured by occupying the central
processor with a task that is known to require conscious attention. If
the operation being studied interferes with the execution of the standard
task (or, alternatively, is interfered with), then it can be said to require
conscious attention.

One of the most important paradigms for measuring and isolating
mental operations is the form of mental chronometry introduced by Posner
and Mitchell (1967). This paradigm requires subjects to match given
stimulus pairs as "same" or "different" according to specified criteria
such as physical or name identity. This paradigm was developed and
elaborated as one of the major tools, not only for Posner and his associates,
but also for the other investigators on the project (such as Schaeffer on
semantic memory). It was with this paradigm, for example, that Posner and
his associates demonstrated that physical and name codes for the same
stimulus were isolable subsystems and gave rise to codes with different
properties. Moreover, they further demonstrated that the matching of
physical forms and the abstraction of the names for these same forms were
mental operations that were performed in parallel.

Posner has provided us several integrative summaries of his work over
the course of the project. An early and important integration anpeared
in his chapter on "Abstraction and the process of recognition" (1970).

Here the work resulting from the matching paradigm was tied to his work with Keele on the genesis and retention of abstract ideas. This bridge to pattern recognition also served as a bridge to some of Attneave's work and that of Hyman and his associates on pattern learning. Other important integrative papers are "Coordination of internal codes" (1972), "Attention demands of movements" (with Keele, 1969), "Skill learning" (with Keele, in press), "On the functions of consciousness" (with Klein, 1972), "Traces, concepts, and conscious constructions" (with Warren, 1972), "Components of attention" (with Boise, 1971), and "On the selection of signals" (with Klein, Summers and Buggie, 1973).

The framework provided by the forthcoming book on Memory and Thought divides the study of cognition into two categories: statics and dynamics. The statics of cognition deals with how information is represented in memory. Memory systems differ in their characteristics and in the codes they employ. The two major characteristics are long-term memory and activated memory. Activated memory consists of both short-term memory (immediate memory of stimulus input or sensory analysis) and operational memory (items retrieved from long-term memory). It is activated memory that provides the key to thinking. It is in activated memory, with its limited capacity, that the right combination of information for solutions to problems will or will not occur.

The memory codes are iconic, enactive, and symbolic. These codes usually develop in parallel and which is most salient depends upon a variety of contextual, strategic, and other factors.

The dynamics of cognition deal with the mental operations which are performed on these codes. Operations require time and they may also

require space. When they require space, of course, they involve consciousness. The effectiveness of the problem solver may depend on such things as which operations he can automate (so as to bypass consciousness) and on developing effective ways to retrieve information from long-term storage in such a way that just that combination required will occur together in activated memory.

Posner's most recent work studies the components of attention from both the behavioral and the physiological perspective. Using both his matching paradigm and his newer techniques which measure the evoked potential, Posner has demonstrated how alertness and selectivity, while both enhancing speed of reaction, are separate and independent processes. Alertness, for example, affects the speed of reaction to both same and different reactions alike; selectivity affects the reaction to only one of these components (usually "same"). Selectivity reduces errors as well as facilitating speed of response to the primed target; alertness increases speed of reaction in general without reducing errors and may increase errors. This work suggests an organism that constructs models of the input (expectation) to which it reacts with efficiency and minimal capacity. When the input does not match the internal model, however, an orientation reaction occurs and organism devotes its limited capacity and conscious attention to the discrepancy.

Here we have another potential bridge between Attneave and Posner. In Attneave's earlier work, he developed the notion of perceptual economics. The perceiver was attuned to strip redundancy from the input so as to attend to or cope with points of maximum information (deviation from expectancy). This was a schema-with-correction notion. It is a notion which

now provides a bridge between Attneave, Reicher and others and Posner.

4.4. Analog and digital: The work of Hyman

One attribute on which coding systems seem to differ is that of analog versus digital. In the perceptual area, such as the psychophysical models of Fagot and the spatial model of Attneave, the system into which stimulus input is coded or represented is characterized as a continuous medium or space. Even the language and the mathematics is that of continua and analysis. In the cognitive area, on the other hand, the system into which the stimulus input is coded is more often characterized as a discrete set of categories or nodes. The language and mathematics, when applied, is usually that of set theory, the algebra of classes and graph theory. We all agree that both continuous and discontinuous systems characterize human perception and cognition. The problem has been how to coordinate this knowledge into one model or theory. At the moment, most formal models seem to be exclusively analog or digital in nature.

In our project when we talk about "abstraction" and "generation" or when we talk about the "coordination of internal codes" we explicitly or implicitly refer to analog-to-digital and digital-to-analog transformations. One possible link between analog and digital codes is that analog codes seem to characterize more naturally that form of information processing that is done outside the central processor. Preprocessing of stimulus information seems heavily analog in nature; execution of motor programs below the level of conscious control or awareness also seems analog in nature. Some versions of the logogen model and statistical decision theory may suggest clues as to how the analog-digital interaction can be handled.

The logogen model implies an analog-to-digital conversion in that stimulus input to a logogen adds up continuously until a certain threshold point and then the logogen is set off in a discrete manner. Statistical decision making also implies the imposing of a discontinuity upon a continuous space or dimension.

Hyman and his associates began a series of experiments on pattern classification with this analog-to-digital relation in mind. We deliberately set out, in these experiments, to provide a bridge between the work and theories of Attneave and those of Posner. The experiments and concepts were based upon the earlier work of Attneave on "schema-with-correction" and the more recent work of Posner and Keele on the genesis and retention of abstract ideas. The stimulus patterns and the experimental paradigm was taken directly from the Posner and Keele studies. The stimulus patterns were dot patterns. Subjects are shown examples of these patterns and learn to classify them into two categories. Once they can correctly classify the exemplars into the appropriate categories they are then tested on a wide variety of patterns, many of them new, to see how they will classify patterns not previously encountered. Our experiments differed from those of Posner and Keele in two ways. We used only two categories. And, more importantly, our patterns did not differ from each other in random ways, but rather in systematic ways along two dimensions--height and width.

Our patterns could be seen as being drawn from the same continuous Euclidean space with dimensions of height and width. In fact, our multidimensional scaling of similarity judgments made by a panel of judges,

confirmed our belief that subjects would respond to these patterns as if they were drawn from a continuum of patterns that vary in two dimensions that correspond to the physical dimensions of height and width. Our requirement that subjects learn to classify patterns within this space as belonging either to one or another of two categories in effect requires the subject to impose a digital code upon an analog system.

We were concerned with three possible models of how subjects could accomplish this task. One model, the Exemplar Model, says the subject stores a unique description of each exemplar along with the associative bond corresponding to name of the category to which it belongs. In this model, the subject recognizes a new pattern by comparing it, either serially or in parallel, with all of the stored exemplars. If, on the average, the test pattern is closer to the exemplars representing category A, he classifies it as an A; otherwise as a B.

The second model, the Prototype Model, is based on the findings of Posner and Keele. This model says that, during learning or later, the subject will construct a composite figure or surrogate pattern (the prototype) based upon the central tendency of all exemplars for that category. In this case, when presented with a test pattern, the subject need retrieve and compare it to the surrogate of each category. Such a strategy could achieve considerable economy, especially if there were many exemplars and if comparisons were done serially.

The third model, the Rule Model, sees the subject abstracting a rule for classifying the patterns based upon the dimensions on which they vary. He might learn during acquisition or the test phase that all exemplars of A are taller than they are wide. In this case, he need not retrieve either

stored exemplars or prototypes when confronted with a test pattern.
Instead, he need only determine if the pattern is taller than it is wide;
if yes, then he classifies it as an A; if no, he classifies it as a B.

Our original expectations were that subjects, in fact, use strategies
consistent with all three models, but each model is more appropriate at
different stages of mastering the pattern task. At the earliest stage of
learning, especially when first presented with an exemplar, we felt that
the subject would have to rely on a process implied by the Exemplar
Model. At a somewhat later stage, especially when there were several
exemplars, we felt that the Prototype Model would become appropriate.
And, finally, especially during the testing phase in which a large variety
of patterns would emphasize the dimensions of variation, the Rule Model
might become dominant.

As can be expected, the Exemplar Model and the Prototype Model are
quite difficult to distinguish. Our results suggest that subjects perform
according to one or the other of these models, but no transitions within
a subject take place. More clearly, our subjects rarely, if ever, perform
according to the Rule Model. This was so even when we told the subjects
the rule in advance.

We are currently reanalyzing the data according to a model more in
line with statistical decision theory and Thurstonian models of classifi-
cation. It is clear from both our scaling and pattern recognition data
that subjects perceived our patterns as differing from one another along
a single dimension within a Euclidean space. The "A's" tend to be skinny
(taller than wide) and the "B's" tend to be squat (broader than tall).

A qualitative picture of their behavior would be something like this.
A test pattern is located on this dimension. If it is near the border

between category A and category B, the subject will be inconsistent in
how he classifies the pattern and he will take a long time to classify
it. If the test pattern is not near the border, he will consistently
classify as an A or a B depending upon its direction from the border.
His speed of classification, however will depend upon how far the test
pattern is from the border. If it is moderately far from the border,
he will be reasonably fast and accurate. But if it is very far from
the border, his speed of classification will begin to slow down again.
It is this last fact that makes the Rule Model inapplicable.

What is suggested is a model of this sort. The subject codes
the test pattern simultaneously in two ways. He codes it in terms of
where it is located on a continuum (analog coding) and he codes it in
terms of how close it is to an idealized member of a given class (the
prototype). The prototype is a digital code in the sense that it is
a discrete region of the space. The classification is digital as well,
since it represents a partition of this space.

This work will probably be completed within the next six months.

4.5. Other Inputs: Fagot, Beck, Haller, Hintzman, Reicher, Schaeffer,
Wickelgren.

The Final Technical Report for the first four years adequately covers
the contributions of the remaining investigators as well as the visiting
scholars. These investigators used whatever time they devoted to the
present project during its fifth year to finish and write up work already
reported in the preceding report. Some new work was initiated by
Dr. Jeannette Silveira as followup on her dissertation on incubation in

problem solving. She confirmed some of the results of that dissertation, but failed to come up with any new findings in a series of experiments to see how different methods of instruction would facilitate later problem solving.

Reicher and Hyman initiated some preliminary experiments on reading and comprehension. These provided the basis for a new research proposal to apply findings from the present project to the study of how subjects comprehend instructional materials. Charles Snyder completed his doctoral dissertation on individual differences in imagery. Snyder conducted four experiments in which he related the vividness and controllability aspects of imagery ability to performance in a variety of tasks, including sketching, problem solving, spatial relations, same-different matching, and detection, naming and classification of letters. Controllability of imagery was significantly correlated with sketch quality, problem solution time, scores on a test of space relations, several aspects of letter detection, same-different matching times, and rate of 'mental rotation' in matching and classification tasks. Vividness of imagery was related to sketch quality and to reproduction measures in general.

Carol Conrad also completed her doctoral dissertation during the fifth year. She used the procedure that Warren developed during his dissertation to determine if abstraction continues beyond the point necessary to perform certain tasks. In Conrad's case, she wanted to see if, when words are interpreted in the context of a sentence, the alternative meanings not implied by the context are also looked up. She was able to demonstrate that, in fact, there does seem to be a separate lexical lookup

stage that precedes the disambiguation of a word when it occurs in a sentence. For example, when subjects are confronted with the sentence, "The sailors sailed into the port", they apparently retrieve the meaning of port that refers to "wine" as well as that which refers to the appropriate meaning of "harbor".

5.0. The Automated Laboratory

A full description of the development and current status of our Automated Laboratory was provided in the Final Technical Report for the first four years. In that description we mentioned plans for developing a higher level language called Experiment Writer. Since then, we have perfected and implemented this language so that it is now being used on a routine basis. Graduate students and experimenters who have never learned Fortran or computer programming can now be taught within a matter of hours how to use our Automated Laboratory to set up and run a variety of experiments.

We also have finally cleared all hurdles for renovating the basement of Straub Hall to serve as the new site for the Automated Laboratory. By moving into this new location, we overcome the few remaining hurdles towards making the laboratory a facility that can be used simultaneously and effectively by all the experimental psychologists who have governmental contracts.

6.0. Extensions and Ramifications

The major focus of the five-year project on Coding Systems in Perception and Cognition was on gaining maximal generality of our findings across all the areas of experimental psychology from sensory psychophysics through semantic memory. For the most part, we used stimulus inputs

that were relatively meaningless and confronted our subjects with tasks that required them to focus upon the "medium" rather than the "message". Not only were our stimulus inputs semantically meaningless, they were emotionally neutral as well.

Such constraints were deliberate. They served the purpose of enabling us to isolate subsystems of human processing that cut across a wide variety of tasks. And they provided us with a basis for what we hope is an integrated picture of the human as a general processor of information.

But, by the same token, these constraints limit our generalizability in the sense that we have still to demonstrate that the same processes and codes apply when we place the human in naturalistic settings where the information he must cope with is rich in semantic significance and emotional coloring.

Actually, even before the end of this project, some of the work was moving towards more realistic stimulus inputs and real-life tasks. The work of Schaeffer and Conrad on semantic memory is one example. Hyman and Reicher's preliminary experiments on reading and comprehension is another. Still other cases would be Haller and Reicher's study of high skilled performance such as sight-reading in musicians; Schwank's study of the Oregon electoral ballot; and Silveira's dissertation on incubation in problem solving.

Currently, many of the investigators on the project are engaged in, or making plans for, research that will help to extend and apply our findings to social and practical problems. Keele has been working on

ways to employ our findings in coping with environmental problems such
as noise, pollution, crowding and over-population. In our renovated
facility at Straub Hall, we have included an environmental room which
will be used to study the effects of noise and pollution upon human
information processing.

We have already mentioned how Posner has extended the range of
applicability by applying our findings to the problem of human thinking
and problem solving. We have also mentioned the extension to physiologi-
cal indices as well as our behavioral indices in our study of attention.
Posner's work on attention and alertness has provided one way in which
emotional and arousal components are naturally entering into what had
up to now been the study of "cold cognition". Indeed, because of our
interest in bringing emotional aspects of coding into the picture, we
have organized a seminar with our social psychological colleagues on
"hot cognition". We have also been using emotionally toned words to
study the coding and retrieval aspects of the emotional affect as well as
the cognitive content of stimuli.

Along with this, Hyman has completed a series of studies on aesthetic
preference as another aspect of pattern recognition and retrieval.

The area of semantic memory is being expanded in a major project
to apply our findings to a very practical problem--that of comprehending
instructional material. Hyman, Reicher, Schaeffer and Wickelgren have
joined together to study this problem. We expect help from the other
investigators in the project who are also anxious to see how our findings
can be extended to the worlds of reading, education, and related matters.

We have seen other possible applications of our work being de-
veloped. A doctoral dissertation by Karen Boise used our apparatus
and matching procedures to compare brain-damaged patients with normals.
The results are promising in enabling us to pinpoint the nature of the
deficit in terms of isolable subsystems that we have been studying.

7.0. ARPA Articles Cross Referenced by Key Words (prepared by Jacelyn Weddell).

The following Key Word List is intended only as a guide, not as a
complete listing of all relevant terms. Contents of articles, as well as
titles, were studied to complete the list. A number of terms which would
be common to a great number of articles in the bibliography have been deleted.
Most efficient use of the list can be accomplished by noting the articles
under a number of related terms and referring to those which are listed
more than once.

ATTENTION

Posner, 1971(b)
Posner & Boies, 1971

ATTENTION DEMANDS

Ells, 1969
Keele, 1968,1970,1972

Posner, 1972(c)
Posner, Boies, Eichelman,
& Taylor, 1969

Posner & Keele,1969, In Press
Posner & Warren, 1972

ATTENTION, DIVIDED

Atwood, 1969, 1971
Keele, 1968
Lewis, 1970(b)
Schaeffer & Wallace, 1970(b)

ATTENTION,MANIPULATION OF

Posner, 1970(a)

ATTENTION, REDUCED

Posner, 1969(b)
Posner, Boies, Eichelman,
& Taylor, 1969

ATTENTION, SELECTIVE

Beck & Ambler, 1972
Hintzman, Carre et.al, in press
Lewis, 1970 (a),(b)
Posner, 1971(b)
Posner & Boies, 1971

ATTENTIVE, PRE-V.S. FOCAL

Beck & Ambler, 1972
Beller, 1970(a)
Eichelman, 1970(a)
Snyder, 1972(b)

ATTENUATION

Lewis, 1970(a),1970(b)

ATTRIBUTE LEARNING

Schaeffer & Wallace, 1968

AUDITORY CODES

Posner, 1970(a),1972(c)
Posner, Lewis, & Conrad, 1972
Warren, 1970

AUDITORY FEATURES

Wickelgren, In press(b)

AUDITORY PERCEPTION

Atwood, 1969,1971
Lewis, 1970(a)

AUTOMATION

Posner, 1969(b)
Posner, Boies, Eichelman
& Taylor, 1969
Posner & Keele, In press

BIAS

Fagot & Stewart, 1970(b)

BINOCULAR VISION

Attneave & Frost, 1969

BISECTION

Adams, Fagot & Robinson, 1970
Fagot & Stewart, 1970(b)

BISENSORY TASK

Lewis, In press

BRIGHTNESS

Fagot, & Stewart, 1969(a),1969(b)
1970(a)

CONJUNCTION

       Schaeffer & Wallace, 1968

CONSOLIDATION

       Adams, Submitted
       Wickelgren & Berian, 1971

CONSTANCY

       Attneave, 1971
       Frost, R., 1971
       Olson, 1970(b)

CONSTANT BRIGHTNESS

       Fagot& Stewart, 1969(a),1970(a)

CONTEXT

       Conrad, 1972(b)
       Hintzman, Block & Summers, Submitted

CONTEXT-SENSITIVE CODING

       Wickelgren, In press (a)

CONTEXTUAL CUES

       Hintzman,Block & Summers, Submitted

CONTROLLABILITY

       Snyder, 1972(a)

CONVERGENCE

       Frost, R., Submitted

CREATIVITY

       Silveira, 1971

CROSS-MODALITY

       Attneave, 1969

CUES, CONTEXTUAL

       Hintzman, Block & Summers, Submitted

CUES, MOTOR

       Laabs, 1971
       Posner, 1969(b)

CUES, MULTIPLE

       Laabs, 1971

CUES, SENSORY

       Snyder, 1972(b)

CUES TO FORGET

       Block, 1970

DATA EQUIVALENCE

       Adams, Submitted
       Adams, Fagot & Robinson, 1970

DECAY

       Posner, 1970(a)
       Warren, 1968
       Wickelgren & Berian, 1971

DECISION UNIT

       Schaeffer & Wallace, 1970(a)

DECISIONS, SKILLED PERFORMANCE

       Posner & Keele, 1969

DECISIONS, TIME

       Keele, 1970

DELAY

       Beck & Ambler, 1972
       Boies, 1969
       Posner, 1970(a)
       Posner & Keele, 1970
       Wickelgren & Norman, 1971

LEARNING, INCIDENTAL

Hintzman & Block, Submitted

LEARNING, RULE

Schaeffer & Wallace, 1968

LEARNING, TRANSFER OF

Schaeffer & Wallace, 1968

LETTER MATCHING

Boies, 1969,1971
Buggie, 1970
Eichelman, 1968,1970(b),1970(c)
Posner, 1970(a),1970(b)
Posner & Boies, 1971
Posner & Klein, 1972
Posner & Warren, 1972
Turnbull, 1971

LEXICON

Conrad, 1972(b)
Wickelgren, In press (a)

LIMITATIONS

Posner & Keele, In press
Posner & Klein, 1972

LINGUISTICS

Conrad, 1971, 1972(a),1972(b)
Hughes, 1970
Schaeffer & Wallace, 1968, 1969,
 1970(a),1970(b)

LIST DISCRIMINATION

Hintzman, Block & Summers
 Submitted
Hintzman & Waters, 1969,1970

LIST MEMBERSHIP, JUDGMENTS OF

Hintzman & Block, Submitted
Hintzman, Block & Summers,
 Submitted

LISTENING, DICHOTIC

Lewis, 1970(a),1970(b)

LOCI, METHOD OF

Atwood, 1969,1971

LOCATIONS

Attneave, 1969
Attneave & Olson, 1971
Laabs, 1971
Posner & Keele, In press

LOGOGEN MODEL

Schaeffer & Wallace, 1970(a)

LOGOGENS

Lewis, 1970(a)
Posner, 1972(c)
Posner & Warren, 1972
Warren, 1970,1972

LONG TERM MEMORY (LTM)

Beller, 1971
Boies, 1971
Conrad, 1971,1972(a),1972(b)
Hintzman, 1970,1972
Hintzman & Block, 1970,1971,
 Submitted
Hintzman, Block & Inskeep, In
 press
Hintzman, Block & Summers,
 Submitted
Hintzman & Waters, 1969,1970
Keele, 1969,1972
Posner, 1970(a)
Posner, Boies, Eichelman,
 & Taylor, 1969
Posner & Keele, 1970
Posner & Warren, 1972
Schaeffer & Wallace, 1968,1969,1970(a)
Wickelgren & Berian, 1971

LUMINANCE

Fagot & Stewart, 1969(a),1970(a)

NODE

Buggie, 1970

NONPARAMETRIC SCALABILITY

Fagot & Stewart, 1970(b)

NUMERICAL RESPONSE METHODS

Fagot & Stewart, 1969(b)
Fagot, Stewart & Kleinknecht,
Submitted

OPEN LOOP

Posner & Keele, In press

ORGANIZATION

Conrad, 1971, 1972(a)
Frost, N., 1970,1971(a)
Schaeffer & Wallace, 1969,1970(a),
1970(b)

ORIENTATION

Buggie, 1970
Snyder, 1972(a)

PARALLEL, PROCESSES

Beller, 1970(a)
Frost, N., 1971(b), In press
Hintzman, Carre, et. al., In press
Johnson, 1968
Posner, 1970(a),1972(c)
Posner & Boies 1971
Posner, Lewis & Conrad, 1972
Posner & Taylor, 1969
Posner & Warren, 1972
Reicher, 1969
Wickelgren, In press (a)

PARTIAL CODES

Beller, 1971

PARTIAL REPORT

Snyder, 1972(b)

PATTERN JUDGMENTS

Posner, 1970(a)

PATTERN RECOGNITION

Buggie, 1970
Posner, 1970(a),1972(b)
Posner & Keele, 1970

PERCEPTION

Attneave, 1969,1971,In press
Attneave & Frost, 1969
Attneave & Olson, 1971
Beck & Ambler, 1972
Eichelman, 1970(a)
Fagot & Stewart, 1969(a),1969(b)
1970(a)
Fagot, Stewart & Kleinknecht,
Submitted
Frost, R., 1971, Submitted
Johnson, 1968
Kleinknecht, 1971
Murdoff, 1971
Olson, 1970(a),1970(b)
Posner, 1971(b),1972(b)
Posner & Warren, 1972

PERCEPTION AND IMAGERY

Posner 1972(c)

PERCEPTION, DEPTH

Attneave, 1971
Olson, 1970(b)

PERCEPTION, SPACE

Attneave, 1971
Attneave & Frost, 1969
Frost, R., 1971
Olson, 1970(b)

PERCEPTUAL CODES

Attneave & Frost, 1969
Hintzman, Block & Inskeep, In press
Johnson, 1968

PERCEPTUAL UNITS

> Johnson, 1968

PFANZALGEL'S MEASUREMENT MODEL

> Adams, Fagot & Robinson, 1970
> Fagot & Stewart, 1970(b)

PHI-LAW

> Fagot & Stewart, 1969(a),1970(a)
> Kleinknecht, 1971

PHONETIC CODE

> Wickelgren, In press (b)

PHOTOPIC VISION

> Fagot & Stewart, 1969(a)

PHYSICAL CODE

> Beller, 1971
> Boies, 1969,1971
> Posner, 1970(a),1972(c)
> Posner & Boies, 1971
> Posner & Taylor, 1969
> Posner & Warren, 1972

PITCH

> Attneave & Olson, 1971

POSITION JUDGMENTS

> Hintzman, Block & Summers,
> Submitted

POWER FUNCTION

> Fagot & Stewart, 1969(a), 1969(b)
> 1970(a)
> Kleinknecht, 1971

PRACTICE

> Boies, 1971
> Posner & Keele, In press

PRAGNANZ

> Attneave, 1971
> Attneave & Frost, 1969

PREPARATION

> Posner & Boies, 1971
> Posner & Keele, In press
> Silveira, 1971

PREPROCESSING

> Buggie, 1970
> Schaeffer & Wallace, 1968

PRIMACY EFFECT

> Hintzman, Block & Summers,
> Submitted

PRIMING

> Beller, 1971
> Posner & Klein, 1972
> Wickelgren, In press(a)

PROACTIVE INTERFERENCE

> Block, 1970,1971
> Hintzman & Waters, 1969

PROBLEM SOLVING

> Silveira, 1971

PROCESSING, AUTOMATIC

> Posner & Warren, 1972

PROCESSING CAPACITY

> Boies, 1971
> Posner & Boies, 1971
> Posner, Lewis & Conrad, 1972
> Schaeffer & Wallace, 1970(b)

PROCESSING, HIERARCHICAL

> Conrad, 1971,1972(a)
> Posner, Lewis & Conrad, 1972
> Schaeffer & Wallace, 1969

RECALL, FREE

Frost, N., 1970,1971(a),1971(b)
In press
Hintzman, In press
Hintzman & Block, Submitted
Hintzman, Block & Inskeep, In
Press
Hintzman, Block & Summers,
Submitted
Hintzman, Carre, et.al., In
Press
Hughes, 1970

RECENCY EFFECT

Hintzman, Block & Summers,
Submitted
Hintzman & Waters, 1969,1970
Umilta, Snyder & Snyder, 1972

RECENCY JUDGMENTS

Hintzman & Block, Submitted

RECEPTORS

Attneave, 1969

RECOGNITION MEMORY

Beller, 1970(a)
Block, 1970,1971
Buggie, 1970
Conrad, 1972(b)
Frost, N., 1971(b), In press
Hintzman, 1970
Hintzman, Block & Inskeep,
In press
Hintzman, Block & Summers,
Submitted
Posner, 1970(a)
Posner & Keele, 1970
Reicher, 1969
Reicher, Ligon & Conrad, 1969
Rogers, 1972
Snyder, 1972(a)
Taylor, 1969(b)
Wickelgren & Berian, 1971
Wickelgren & Norman, 1971

RECOGNITION, SPEECH

Wickelgren, In press(a), In press (b)

REDUNDANT INFORMATION

Schaeffer & Wallace, 1968

REHEARSAL

Block, 1970, 1971
Laabs, 1971
Posner, 1970(a), 1972(c)
Posner & Boies, 1971
Warren, 1968

REMINISCENCE

Silveira, 1971

REPETITION

Eichelman, 1970(c)
Fagot & Stewart, 1970(b)
Hintzman, 1970
Hintzman,& Block, 1970,1971
Submitted
Hintzman & Waters, 1970
Posner, & Warren, 1972
Umilta, Snyder & Snyder, 1972

REPETITION EFFECT

Hyman & Umilta, 1969
Keele, 1969
Posner, 1969(b)

REPRESENTATION

Boies, 1971
Hintzman, Block & Inskeep, In press
Posner, 1970(a)
Posner & Boies, 1971
Taylor, 1968,1969(a)

REPRESENTATIONS, ABSTRACT

Posner, 1972(c)

REPRODUCTION

Keele, 1968
Laabs, 1971
Posner & Keele, In press

Reicher, Haller & Aitken,
    Submitted

REPRODUCTION CODE

Wallace, 1971

RESPONSE BIAS MODEL

Fagot & Stewart, 1970(b)

RESPONSE COMPETITION

Hintzman, Block & Summers,
    Submitted
Keele, 1970,1972
Lewis, 1970(a)
Posner & Boies, 1971
Posner & Keele, 1969

RESPONSE PRIMING

Posner & Klein, 1972

RESPONSE SELECTION

Ells, 1969
Keele, 1970
Lewis, 1970(a)
Posner & Boies, 1971
Posner & Keele, 1969

RESPONSE-STIMULUS INTERVAL (RSI)

Eichelman, 1970(c)
Umilta, Snyder & Snyder, 1972

RETENTION

Boies, 1969
Hintzman, Block & Summers,
    Submitted
Posner, Boies, Eichelman &
    Taylor, 1969
Posner & Keele, 1970, In press

RETRIEVAL

Atwood, 1969, 1971
Conrad, 1971,1972(a),1972(b)

Frost, N., 1971(b),In press
Hintzman & Block, Submitted
Hintzman, Block & Summers,
    Submitted
Keele, 1969,1970,1972
Posner, 1970(a),1972(c)
Posner & Taylor, 1969
Posner & Warren, 1972
Schaeffer & Wallace, 1969,1970(a),
    1970(b)
Wickelgren & Berian,1971

RETROACTIVE INTERFERENCE

Block, 1970,1971

RIVALRY

Posner, 1972(c)

RULE LEARNING

Schaeffer & Wallace, 1968

SALIENCE

Schaeffer & Wallace, 1968

SAME-DIFFERENT JUDGMENTS

Boies, 1969,1971
Eichelman, 1968,1970(a)
Johnson, 1968
Posner, 1970(a),1970(b)
Posner, Lewis & Conrad, 1972
Rogers, 1972
Schaeffer & Wallace, 1968,1970(a),
    1970(b)
Taylor, 1968,1969(a),1969(b)

SCALING

Adams, Fagot & Robinson, 1970
Attneave & Olson, 1971
Fagot & Stewart, 1969(b)
Fagot, Stewart & Kleinknecht,
    Submitted
Kleinknecht, 1971

SHAPE

Attneave & Frost, 1969
Frost, N., 1970,1971(a),1971(b)
   In press
Frost, R., Submitted
Laabs, 1971
Olson, 1970(a)

SHORT TERM MEMORY (STM)

Beller, 1971
Block, 1970,1971
Highes, 1970
Johnson, 1968
Laabs, 1971
Reicher, Ligon & Conrad, 1969
Stewart, 1969
Taylor, 1968,1969(a)
Warren, 1968
Wickelgren & Berian, 1971
Wickelgren & Norman, 1971

SIGHT READING

Reicher, Haller & Aitken,
   Submitted

SIGNAL DETECTION

Reicher, Ligon, & Conrad, 1969

SIMILARITY

Beck & Ambler, 1972
Frost, N., 1971(a), In press
Lewis, 1970(a)
Olson, 1970(b)
Posner & Taylor, 1969
Reicher, Ligon & Conrad, 1969
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The bibliography contains a small proportion of articles that were not directly credited as being sponsored by the present ARPA contracts. Because our investigators sometimes had other contracts or grants which overlapped with the present project, it was sometimes quite arbitrarly how the credit for sponsorship was assigned. It was felt that articles published by investigators which were intimately related to the purposes of the project even though at the time they were assigned to other contracts should be included here for completeness.

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